Some technological aspects of fast nuclear reactors

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At first, we are ascending to axioms and then are descending to practice.
Francis Bacon

The technological strategy for developing of fast nuclear reactors means more than their creation in a new kind as it is necessary not only to answer the question what to do but also how to do that by the best way. As far back as Democritus was stating: "The substance of the matter not in fullness of knowledge but in fullness of comprehending" that includes apart from the knowledge also the skill. One cannot design qualitatively a new energy system without comprehending of all mechanisms and processes in such system, i.e. not only without their basic and applied research but also without controlling them well in practice what is the technological maintenance of assigned materials quality.

For example, pure sodium (with the melting point of 98 °C and the boiling temperature of 883 °C) is offered all over the world as the coolant for a fast nuclear reactor thanks to the best thermal, hydraulic, and neutron-physical properties. However the boiling temperature of this metal is close to the operating temperatures of the nuclear reactor and this coolant is very active chemically in environment. So, sodium is easily being ignited in contact with air and forms many radioactive aerosols from the first-loop coolant. In the contact with water, even solid sodium explodes, not to mention the liquid one [1].

This problem can be solved only by using a double polar-metals eutectic in which, sodium gives electrons from itself and a second component accepts them, i.e. is the electro-negative one and serves as a strong oxidizer [1, 2]. It can be the eutectic $\mathrm{Na_{0.93}Tl_{0.07}}$ which lowers a chemical activity of sodium, automatically maintains the oxygen-free technology of the liquid-metal coolant in nuclear reactor [3], decreases its melting point up to 64 °C [4], and increases its boiling temperature up to 1077 °C [5].

The double system $\mathrm{Na-Tl}$ forms the homogeneous solution of thallium in sodium to the left of the eutectic point ($\mathrm{Na_{0.93}Tl_{0.07}}$) and then, does polymorphic transition (in the eutectic point) into a colloidal solution with quasi-solid clusters $(\mathrm{Na_6Tl})_n$ in liquid sodium [3, 5]. Just they provide the nuclear and environmental safety of modified coolant by automatic shut-down of sodium fires outdoors [1]. The point is that, the oxygen effect in the eutectic is less than the one in pure sodium because oxygen is dissolved only in clusters $(\mathrm{Na_6Tl})_n$ but its solubility in the eutectic is controlled by fall-out of sodium oxide [3]. Probably, this will allow to exclude a cold trap in reactor with such coolant and to use only a filter in order to be extracting thin-dispersed oxide particles.

A similar situation arises in the lead-cooled fast reactor. Though lead is chemically almost neutral (with the melting point of 327 °C and the boiling temperature of 1745 °C), its corrosive activity is so high that the coexistence of this coolant with structural materials in the fast nuclear reactor demands huge technological efforts even at moderate temperatures, not to mention the high ones. Besides, such-coolant hydrodynamics requires rather wide passages between fuel elements in the core of reactor and using of a dense fuel [1].

However one can improve the lead coolant by applying the eutectic $Pb_{0.83}Mg_{0.17}$ (with the melting point of 249 °C and practically with the same boiling temperature of 1750 °C [5]) as the modified lead coolant. Thanks to magnesium which is the strong reducing agent, this eutectic dissolves oxides on the surface of fuel cladding, provides the oxygen-free-technology of this coolant, and the effective heat transfer from the fuel element due to the good thermal contact of coolant with its surface [3, 6].

Besides, this eutectic decreases the corrosion of structural materials there thanks to the low oxidizing potential of magnesium which disintegrates precipitates of complex oxides being the main impurity transfer in the non-isothermal liquid-metal loop [1]. Indeed, all precipitates before their fall-out from the liquid metal have a microscopic form unstable at decreasing temperature as well as in any colloid solution [7]. Therefore they become active carriers of steel components of a hot part of liquid-metal loop into the cold one if the concentration of dissolved oxygen in the coolant exceeds 10^{-17} %. Below of this level, the corrosion conditions can improve considerably.

Here are two concrete examples that indicate additional basic and applied researches needed for development of fast nuclear reactors by means of eutectic modification of liquid-metal coolants. Such technological development is possible thanks to the functional synergism of the polar components of eutectics. Their functional difference improves the operation properties of the coolant to such an extent that the technical characteristics of the fast reactor will be easily optimized as well as its operational safety.

Thus, profound understanding the physical and chemical processes in the liquid metals allows improving the properties of liquid-metal coolants for fast nuclear reactors by means of correcting the composition of these coolants and the eutectic modification of them can be the best decision.

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